QUANTITY OF WATER CONSUMED IN IRRIGATION.

By W. W. CULCHETH, M. Inst. C.E.

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I.—Introductory Remarks.

1. In a country like Australia, where so little in the way of irrigation has been accomplished, the experience of other countries must be depended on. The author at first intended giving the results of his own experience and observations (extending over a period of more than twenty years) on irrigation generally in India, thinking the information would be useful to many at the present time; but the limits prescribed for this paper would not permit of much more than one branch of the subject—the quantity of water required for irrigation—being treated in sufficient detail to be really of any practical use.

2. The quantity of water required for irrigation is a most important point in connection with the probable success of any proposed scheme; nevertheless, opinions of engineers are much divided on the subject. Numerous experiments and measurements of water actually consumed have been made, often giving under various forms widely differing results. In many cases, however, the differences are more apparent than real, being in the conditions of the cases rather than in the results themselves. Shortly before leaving India, the author made several notes from the official report (the latest he has seen) on the irrigation of the North-western Provinces (India) for the year 1875-76. At the time, the author had not arrived at the conclusions about to be noticed, hence there will appear an incompleteness of information on certain points, which cannot at present be remedied. From these and other notes, some useful results may be deduced, which the author will endeavour to give in a convenient form for use in Australia.

3. It is sometimes assumed that because a given supply of water has been made to irrigate so many acres, or, expressed in the usual way, because a "duty" of so many acres per cubic foot per second of canal discharge has been

obtained in one locality, the same duty may be estimated for elsewhere, notwithstanding differences of climate, of soil, in the quantity of water available, in the length of canal the water has to traverse before reaching the fields, in the mode of using the water, in the crops grown, in the number of waterings they require, and in several other respects. The number of acres irrigated per cubic foot per second of discharge may be sufficient information to base calculations on when one country only is concerned, and there are certain points of resemblance in the schemes, though not always even then; but when the information is required for application in another country, and under wholly different conditions, it is too vague to be of much use. The following instances of the actual duty obtained on certain canals in various countries may be taken in illustration of this :—

Countries and Canals.	Acres irrigated per cubic foot per second of supply. Extremes.	Aver-age.	Authorities.
India { Eastern Jumna Canal..	184 to 291	216	Official Report* — Results of ten years, 1866 to 1876.
India { Ganges Canal	154 to 239	190	
Spain—Canals from River Turia	38 to 114	78	Major Scott Moncrieff, R.E.†
Italy { Canals in Lombardy ..	62 to 104	70	Col. Baird Smith, R.E.‡
Italy { ,, Piedmont ..	43 to 106	55	

Even in one canal there are differences; thus in one division of the Ganges Canal a duty of 97 acres only was obtained in 1875-76, while in another the duty was 290 acres; in the cold season only, one division gave 41 acres and another 204 acres (see par. 6).

4. The volume of any stream, which is to be turned wholly into a canal for irrigation, will be consumed as follows :—

(1) By loss at the head itself.

(2) By loss from escapes provided at convenient places to insure the safety of the works.

* Irrigation Revenue Report of the North-western Provinces (India) for the year 1875-76, page 13, par. 23.
† Irrigation in Southern Europe (1868), page 168.
‡ Italian Irrigation (1855), Vol. I., pages 116 to 298.

(3) By loss from evaporation and percolation—
(*a*) In the canal itself.
(*b*) In the distributaries, called in Northern India *rájbahas.*
(*c*) In the village watercourses, called *gúls.*
(*d*) In the small field channels, for the supply of one field only at a time.
(*N.B.*—*c* and *d* might be noticed under one head, but a division is convenient for the purpose of this paper.)

(4) Lost by accidental breaches of banks and by carelessness of cultivators.

(5) Utilised in irrigating the fields.

5. The consumption under these several heads may be more fully explained as follows :—Head (1) represents the difference between the volume of water flowing down the stream and that entering the canal. Head (2) explains the difference between the supply entering the canal and that available for irrigation. The consumption under these two heads may be neglected in this paper, since the results adopted are based on the net supply of water available. The loss under (3) is an item of the greatest uncertainty; it is affected by the lengths of the several portions of the works along which the water has to travel, and by the nature of the soil. A village watercourse is here supposed to be one for the supply of a whole village or a large portion of a village, situated at a distance from a distributary; on the average such may be a mile in length, or, perhaps, a little more. The field channels—for the supply of one field only at a time—may be on the average, perhaps, 200 yards in length. Head (4) is an uncertain quantity; the best way of providing for the loss of water by breaching of banks is, perhaps, to consider it as part of the loss (under 3*b*, 3*c*) from the distributaries, &c., breached, and for the rest (waste by cultivators) to increase the allowance per acre irrigated. By this arrangement this item of loss need not be further considered separately. Head (5) represents the useful employment of the water; every effort should evidently be made to increase the proportion of water under this head by reducing that under the other heads. For practical purposes, the quantity of water consumed may be divided into two parts—(1) that usefully employed in the field, and (2) that lost in the canal and watercourses, large and small.

II.—Results Obtained in India.

6. In 1875-76 the Ganges canal had been in operation over twenty years, but irrigation was not considered to be fully developed. The " duty" obtained from the water, or the area irrigated per cubic foot per second, passing down four of the divisions of the canal (there were altogether seven divisions), and the average duty of the whole canal, in 1875-6 (an average year), were* :—

Divisions of the Ganges Canal.	During the monsoon.	During the cold season.	For the whole year.†	
	Acres.	Acres.	Acres.	
Northern ..	60	41	97	Least duty during the cold season.
Anupshahr ..	46	72	117	,, ,, ,, monsoon.
Cawnpore ..	70	149	220	
Etawah ..	83	204	290	Highest duty each harvest.
Average for the whole canal	65	129	192	

There are two harvests in the year, each ordinary crop being on the ground and requiring water from three to five months. Sugar-cane and garden-produce are exceptional, belonging to both harvests. Cold season crops are chiefly wheat, barley, and other grains (except maize, which is a monsoon crop). Grasses and fodder are seldom irrigated to any great extent in India, particularly during the cold season.

7. It is not quite clear from the author's notes whether the duty of each division refers to the water entering the distributaries of the division, or whether it includes the loss in the canal as well. The author believes the former view is correct, as he is not aware that the canal discharge is gauged elsewhere than near the head and at escapes. Moreover, the duty for the year given in the official report, when comparing several years and the results of two canals together, is 187 acres‡; but when comparing the results obtained in the various divisions, and for the two seasons,

*Irrigation Revenue Report of the North-western Provinces (India) for the year 1875-76, page 9A, table IX.

†The duty for the year is not the sum of the areas for the two harvests, the yearly duty being separately calculated.

‡ Irrigation Revenue Report of the North-western Provinces (India) for the year 1875-76, page 13, par. 23.

separately, the duty is given at 192 acres.* The former would apparently include the loss in the canal, and the latter exclude it; though to avoid error the author has made calculations on each supposition (see App. B).

8. The small duty obtained in the two first divisions in the cold season is explained in the report to be due to the smallness of the area of cold weather crops irrigated, while the high duty in the Etawah division is said to be due to a large area having received only one watering late in the season. So far as the author's notes go, he fails to find any notice taken of the great difference of soil in the various divisions, though it is too important a factor to have been entirely overlooked. The author's notes are, doubtless, incomplete on this point. The low duty year after year in the upper part of the canal, where the soil is light and sandy, and the high duty also year after year in the lower parts of the canal, where much of the soil is heavy and clayey, coupled with other facts to be presently noticed, lead the author to look to the soil as the chief cause of this constant difference. But, in order to allow due weight to the difference in the watering of crops, the author proposes to take (instead of the extreme results shown above) the Anupshahr division as the type of a light soil, and the Cawnpore division as the type of a soil partly sand and partly clay. Fortunately, these are the two divisions with which the author is best acquainted.

9. Taking these two divisions as types of the two soils, and confining further attention to results obtained during the cold season only, since the crops then grown in India more nearly correspond with those grown in the southern portions, at least, of Australia, while the monsoon as a season has no counterpart here, the following figures are obtained :—

——	Area irrigated per cubic foot per second.	Quantity of water used per acre.	Depth of water over area irrigated.	——
	acres.	cubic feet.	feet.	
Light sandy soil ..	72	183,000	4·19	See Appendix D.
Mixed sand and clay soil	149	88,000	2·02	See Appendix D.
Average for the whole canal	129	102,000	2·34	See *a* and *q*, Appendix B.

* Irrigation Revenue Report of the North-western Provinces (India) for the year 1875-76, page 17, par. 38

The figures, as regards the soils, can only be considered as approximations. The average for the whole canal also does not represent the average consumption in fully irrigated fields, since some fields are said to have received only one watering.

10. Results obtained in two other cases may be here briefly noted, leaving till later (see pars. 25 to 27) remarks on their connection with this paper. In 1868-69, a year of great scarcity in the North-western Provinces of India, when the irrigation from the Ganges and Eastern Jumna canals was greater than in any previous year and for several years afterwards, the area irrigated by the Ganges canal, with an average supply of 4668 cubic feet of water per second during the cold season, was 794,794 acres, the duty obtained being 170 acres per cubic foot per second.* In the second case, the author found by measurements of discharge and irrigation from a reservoir in Rajputana during two years, that in five months of the cold season (November to March) an average of 65,000 cubic feet of water was consumed per acre (a depth of nearly 18 inches) in three waterings of about 6 inches each in depth. With a supply of 12 cubic feet per second, gauged at the tank sluices, running for ten hours, an average area of 20 acres was watered daily.

III.—Consumption of Water in the Fields.

11. The author, a few years ago, carefully measured the quantity of water actually used in irrigating cold weather crops from certain wells. It was found in one case that 29,579 cubic feet per acre (a depth of 8·15 inches) had been used, and in another 36,357 cubic feet per acre (a depth of 10·02 inches).† The soil was a light loam, of considerable depth, corresponding, perhaps, with the average land irrigated from the Ganges canal. But since well irrigation is more economical than that from canals, an increase must be made before applying these results to canal irrigation. The author is of opinion that, including the waste of cultivators, an increase of about one-third on the average of the above

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*Professional Papers on Indian Engineering, Vol. VII. (Roorkee, 1870), page 306.

† Professional Papers on Indian Engineering, Vol. II., new series (Roorkee, 1873), page 150.

two quantities would suffice, making the depth, say, 12 inches, and the quantity of water per acre about 44,000 cubic feet, given in four waterings, averaging 3 inches each in depth. This represents the consumption under heads 3*d*, 5, and a portion of 4 (see pars. 4 and 5), and is in the main supported by some results obtained a few years ago on the Bari Doab canal, in the Punjab.* Colonel Baird Smith, R.E., mentions that the result of several experiments made in Italy, in the irrigation of meadows, gave a depth of $3\frac{1}{4}$ inches for each watering; other experiments gave as much as 6 inches, but some of the water was available for other land at a lower level.† Major Scott Moncrieff, R.E., records that 2·36 inches (·06 metre) was found by experiment to be an ample depth for watering in Castile.‡ Many other instances could by given, more or less in support of the author's figures, and some showing higher results; but since it is seldom stated at what distances the fields were from the point of measurement, what was the nature of the soil, and other important particulars, it is fair to conclude that the higher results include considerable loss in the channels leading to the fields; this loss the author is endeavouring to arrive at separately.

12. In a light sandy soil more water would be consumed; but the author is decidedly of opinion that most of the increased consumption above shown to occur in certain divisions of the Ganges canal, is in the canal and distributaries, where they pass through light soil, rather than in the fields. If beds be similarly formed in two different soils, the extra consumption in the lighter soil is an increase of the quantity absorbed during the time each bed takes to fill.§ Thus, supposing a depth of 2 inches of water required in the bed, and that 1 inch is absorbed in average soil before this depth is attained, making 3 inches consumed; then the increase in a light sandy soil would be on the 1 inch, which might become, say, 2 inches, making the consumption in the light soil 4 inches. These figures represent, in the opinion of the author, the depths of the waterings respec-

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* Professional Papers on Indian Engineering, Vol. I., new series (Roorkee, 1872), page 368.

† Italian Irrigation (1855), Vol. II., pages 84, 85.

‡ Irrigation in Southern Europe (1868), page 105.

§ There are 400 or 500 beds to an acre in well irrigation, but fewer in canal irrigation. Evaporation may be neglected for the short time (some three to five minutes only) each of these takes to fill.

tively necessary in the two soils mentioned. In a similar way the author estimates the depth absorbed in a mixed sand and clay soil at half an inch, making the depth of each watering 2½ inches.

13. To make, however, every reasonable allowance for wasteful consumption on the Ganges canal, let a further increase be made to the above estimated depths of waterings. The average consumption per acre being 102,000 cubic feet (see *q*, Appendix B), suppose half be taken as having been used in the fields in four waterings; this would make the depth of each watering in average soil 3½ inches, or one-sixth more than above stated to be necessary; the extra half-inch may be considered as avoidable waste. For very light soil, a depth of 5 inches may be taken (one inch of which is avoidable waste), making the consumpton for the season 20 inches, or, say, 72,000 cubic feet per acre. For a mixed sand and clay soil a depth of 3 inches may be allowed for a watering, and 12 inches for the season, or say 44,000 cubic feet per acre. These quantities are at best approximations, but it is necessary to make some estimate of the kind before the results obtained in India can be put in a form applicable to any other country. The allowance for single waterings will, in the opinion of the author, be found generally applicable to other countries, under a system similar to that adopted in India, whereby water is flowing on to any plot of land for a short time only. Unless in very light soil, or in exceptional circumstances, a depth of 3 to 4 inches seems to be sufficient in European countries as well as in India.

14. The year 1875-76 has been taken as an average year; the duty of the water (either 192 acres or 187 acres—see par. 7) at least corresponds sufficiently with the average duty (190 acres—see par. 3) of the ten years 1866-76 to make it appear such. The quantities of water given in the last paragraph, based on the returns of that year, will, the author believes, be found ample to cover the average consumption in the fields. It must not be overlooked by any one wishing to verify the figures by further experiments that, besides the consumption in the fields, it includes only the loss in the small field-channels, or those for the supply of one field only at a time; loss in village water-courses, or such as are intended to supply several fields at one time, is not included. Probably it would seldom be convenient to gauge the discharge so as to include field-channels only. To allow, therefore, of results obtained in different places

being compared, the points suggested further on (see par. 32) should be noted in every case. And, further, when the field-channels are unusually long, it would be better to consider them separately.

IV.—Loss by Evaporation and Percolation.

15. The remainder of the consumption (averaging, in the case of the Ganges canal for the year 1875-76, 51,000 cubic feet per acre) represents loss by evaporation and percolation in the various channels from the point where the discharge was gauged to the point where the water was issued for individual fields. The total quantity lost daily over the various channels included on this occasion was 192 million cubic feet (see App. B), which will probably be found a near approximation to the loss each year on this canal. The author particularly wishes to urge that this loss, instead of being referred to as so much per cent. of the supply or so many cubic feet per second per mile, as usual hitherto, should be expressed by the depth spread over the whole wetted area of the bed and slopes of the various watercourses. In this form, results obtained on one canal could be applied, as the author will endeavour to show, to other canals, not only in the same country, but also to canals in other countries. The chief points for consideration are noted further on (see pars. 29 and 33).

16. The author has calculated that the loss daily by percolation from the Ganges canal and its distributaries in the cold season of 1875-76 was from 4½ inches to 7¼ inches in depth over the whole wetted surface (see App. B). The lesser depth supposes the loss from the canal itself to be included in the 102,000 cubic feet of water consumed per acre; the greater depth supposes the measurements of discharge to have been made at the distributary heads, thus taking no account of the loss in the canal itself. The latter supposition appears to the author more likely to be correct than the former (see par. 7). Assuming, then, the greater depth as correct, and that the loss in the canal was equal in *depth* to that in the distributaries and minor watercourses, the total loss during the season would suffice to fill a trench having a width equal to that of the wetted perimeter and an average depth of over 90 feet, extending the whole length of canal and dis-

tributaries. Further calculations by the author, to ascertain the loss in various soils (see App. D), show that a depth of 1½ feet would probably be lost daily in very sandy soil; in which case the loss in one part of the canal (the Northern division) during this season would be sufficient to fill a trench nearly 170 feet in width by over 200 feet in depth, for the whole length of the division (about 50 miles). In the first fifteen miles or so, the loss might be double this, or even more (see App. D).

17. The quantity of water lost, when expressed in this form, may appear enormous; but further considerations will perhaps convince those acquainted with the facts to be presently noticed, that it is not more than there is good reason for believing actually takes place. The above quantity, large as it may appear, is, however, small compared with the average volume of water carried by the canal; and special measures to prevent the loss are not worth undertaking. The average loss in the Northern division of the canal was, in fact, only 15·58 cubic feet per second per lineal mile, out of a mean discharge in the season of 4447 cubic feet per second —about one-third (·35) per cent. only. In this form the loss appears insignificant. Where, however, the canal is smaller, and particularly in the distributaries, the proportion lost is much greater. In a small watercourse the loss in a mile may be one-fourth of the discharge at its head (see instance given in next paragraph); here the advantage of puddle in sandy soil is apparent.

18. A Ganges canal officer (Mr. Beresford) some time since gave instances of the loss of water in portions of his (the Anupshahr) division,* which the author, from his recollection of it, would consider not uncommon in that division. Mr. Beresford mentioned a loss of 1·25 cubic feet per second in the first mile of a distributary, having a discharge at the head of 50 cubic feet per second; allowing a wetted perimeter of 16 feet, the depth percolating in 24 hours would be 1·28 feet. In the case of a small watercourse having a head discharge of one cubic foot per second, the loss was ·03 cubic foot in a furlong (·24 cubic foot in a mile); with a wetted perimeter of 4 feet, the depth lost would be ·98 foot per diem; with 3 feet wetted perimeter, the loss would be 1·31 feet in depth. Mr. Login, who was some years ago in

*Professional Papers on Indian Engineering, Vol. V., new series (Roorkee, 1876), page 416.

charge of the Northern division of the canal, has recorded the results of some measurements of the volume of water passing down it in December, 1860, from which the author has calculated that the average daily loss in the first 15 miles was 2·66 feet in depth, and in 31 miles a little further down it was probably 1½ feet (see App. C).

19. The following are some results calculated by the author from data given by Colonel Baird Smith, R.E., for three canals in Italy:—*

	Total discharge per second.	Loss in whole length per second.	Length of canal.	Mean wetted perimeter, estimated by the author.	Average loss.	
					Per mile of canal per second.	Depth over wetted surface in 24 hours.
	c. ft.	c. ft.	miles.	feet.	c. ft.	feet.
Naviglio Grande ..	1851	158	31	100	5	·835
Canal Muzza ..	2652	477	35	150	13½	1·487
,, Martesana..	843	105	28	60	3¾	1·023

These results are merely approximations, as the data are incomplete; but even allowing a considerable margin for errors, the results support the views of the author regarding the excessive loss in certain soils. Some experiments made by the author some years ago, to ascertain what proportion of rainfall might be expected to flow off the ground, showed that about a quarter-inch per hour (6 inches a day) was absorbed. The soil was a light sandy one, in which, by the way, a very fair garden was formed, and the subsoil to a depth of 3 or 4 feet was very similar in appearance to the surface soil. More water would doubtless have been absorbed had a constant head been maintained; all that was done in the experiment was to prevent the ground drying up.

20. In the disposal of sewage there is a system called "intermittent downward filtration," in which sewage is poured in large quantities on land, with a view to its being purified in its passage through the soil. The land must be thoroughly underdrained. At Kendal, England, on one occasion, sewage was flowing on to the land "at the rate of 2,000,000 gallons per diem, equivalent to a depth of 19 inches. . . . The average quantity of sewage flowing out of the land was at least 1,000,000 gallons per diem, equivalent

*Italian Irrigation, Second Edition, Vol. I., pages 219-225, 250-254, and 270-276.

to a depth of 9½ inches over the filtration area. So that, after allowing for the 35 days in each year when the sewage was applied to other land, the enormous depth of 261 feet per annum was purified by the filtration areas, and had been so purified for the last three years."* Such an instance is perhaps exceptional for sewage filtration, but it shows what certain soil can do when the subsoil is thoroughly drained. In the filtration of water for the supply of towns, a very large quantity of water is passed through layers of sand and other material. In London, a depth of from 4½ feet to 18 feet is filtered in 24 hours. The filters are usually formed of 2 feet or 3 feet of sand over 3 feet to 5 feet of gravel and other porous material. This shows what sand, over a porous substratum, can carry off.

21. The canal officer before mentioned, Mr. Beresford, stated that he had seen water just reach an outlet or a field, and no more, and "there are places where a fairly large *kulába*" (outlet) "in a whole week only irrigates two or three fields."† The author recollects that some years ago, when one distributary in the Anupshahr (then called the Fatehgarh branch) division of the Ganges canal was first opened, and for months afterwards, a discharge of something like 80 cubic feet per second in the upper part, was with difficulty able to supply a fourth of this quantity 20 or 25 miles further down; all outlets between had to be closed in order to obtain enough water in the lower part of the distributary to irrigate from it. The author has known several small tanks, where the subsoil was non-retentive, to fill after a heavy fall of rain, and in a couple of days or so, a depth of 6 or 7 feet to soak away. The great facility for the percolation of water offered by very sandy soil, with a porous substratum, is shown by certain rivers in many parts of the world, which are lost in sandy plains—in some cases during the drier portions of the year only, in other cases all the year round. Instances are to be found in parts of Australia.

22. In nearly all these cases a portion of the loss was unquestionably due to evaporation. In canals, evaporation would take place not only from the surface of the water, but also from the moist part of the banks, where water is absorbed and rises above the water-line in the canal. This addition to

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*Proceedings of the Institution of Civil Engineers, Vol. XLVIII., page 207.
†Professional Papers on Indian Engineering, Vol. V., new series (Roorkee, 1876), page 416.

the loss may be unimportant in a large canal, but it may add very materially to the loss from a small watercourse, where it would in similar soil be as much as in the canal, and, consequently, bear a larger proportion to the water surface. Till more is known on the point, it will be convenient to take the wetted perimeter for both evaporation and percolation. The author is of opinion that a quarter-inch per diem may be taken as the average loss from a canal and its distributaries. This might be too much to allow from a large area of deep water, except, perhaps, on very hot, dry, and windy days but it is not too much to allow in hot and dry weather, when irrigation is most needed, as an average for streams, some a few feet deep, and others a few inches only. In a moist and cool climate, and in damp weather also, evaporation would generally be much less than a quarter-inch a day, but under such conditions, irrigation would scarcely be a necessity, unless for what would in India be monsoon crops, which are not considered in this paper, with the exception of rice. In Appendix A, less loss by evaporation has been allowed for rice cultivation, owing to the conditions attending it. Whether evaporation be estimated at a quarter-inch or a little more, since the loss from percolation has been shown to be very great, that by evaporation from water flowing in channels may generally be neglected, except in very clayey soils, where percolation is comparatively little.

23. The depth of water in the canal has not been taken into consideration in the foregoing remarks, because the author's observations on the loss of water from tanks has led him to the conclusion that where the variations of water level are regular, the loss is practically independent of the depth of water in the tank. Doubtless the comparatively great thickness of soil through which the water usually has to pass, is one reason why the effect of a varying depth of water in a tank on percolation is not perceptible. The author sees no reasons for supposing that percolation from any channel, in which water is constantly flowing, would be materially different from percolation from a tank. The author's contention is, that in any given case (tank or canal) the loss in depth would, under ordinary conditions, be practically the same, whatever the depth of water. If the depth of water is one factor, the thickness of soil through which percolation takes place is another factor.

24. The fact of water being often stored in open and unlined reservoirs, formed on the surface of the ground or in

slight excavation, might at first sight be taken as opposed to the foregoing deductions regarding the extent of percolation; but the conditions under which tanks can be successfully formed are essentially different from those pertaining to an ordinary canal. It will suffice here to remark that generally those conditions which are favourable to the construction of a tank restrict the escape of subsoil water, while those favourable to a canal facilitate its escape; and on the free escape or otherwise of the subsoil water, it depends whether percolation is much or little.

V.—Application of Results to other Countries than India.

25. Before showing how to apply the foregoing deductions to canals in other countries than India, it will be well to examine the two cases briefly noticed above (see par. 10) and their bearing on the conclusions drawn by the author. In the first instance, with a larger supply in the Ganges canal in the cold season of 1868-69 by 5 per cent. than that in the cold season of 1875-76, the area irrigated was 39 per cent. larger. It is clear that either there was less waste or the crops received less water in 1868-69—probably both. That the crops received less than the usual quantity of water in 1868-69 is evident from the remark by the Superintending Engineer (Colonel Brownlow, R.E.)—"I have no hesitation in saying that, but for the timely and providential fall of rain in the end of January, there would have been failure of crops, and consequent bitter distress over considerable areas."* There was an unusually large supply of water (6000 cubic feet per second in October, 1868) at the commencement of the season, allowing a larger area than in any previous year being watered; but when, in January, 1870, the supply fell to 4200 cubic feet per second, the canal could not have supplied the wants of the irrigators had not rain fallen. It is thus clear that the crops received less than their normal supply of water—probably an average of three waterings was given instead of four, the usual number.

26. Taking the number of days in the season for convenience of comparison, the same as in 1875-76 (there may

* Professional Papers on Indian Engineering, Vol. VII. (Roorkee, 1870), page 303.

have been more, but this will not be found materially to affect the result), and using the same symbols as in Appendix B, the following results are obtained :—

$$\left.\begin{array}{l} D = 4668 \text{ c. ft. per second} \\ A = 794{,}794 \text{ acres} \end{array}\right\} a = \frac{794{,}794}{4668} = 170 \text{ acres}$$

$$Q = 4668 \times 86{,}400 = 403 \text{ million c. ft.}$$

$$q = 152\ Q \div A = 77{,}132 \text{ c. ft. per acre.}$$

The area of wetted surface (M) over which the loss took place may have been less in 1868-69 than in 1875-76, since there was a less length (by nearly 300 miles) of distributaries in the former year; but probably the larger area irrigated necessitated more village watercourses being in operation, while many of these, doubtless, having been quickly and carelessly formed on an emergency, and used for the first time, the loss in them would be greater than in ordinary years. On the whole, then, perhaps it will be safe to estimate the loss (Q_a) as in both years the same, that is, 192 million cubic feet daily. Then $q_a = 152\ Q_a \div A = 36{,}740$ cubic feet per acre, leaving $q_c = 40{,}392$ cubic feet per acre, which would represent a depth of about 11 inches. Allowing 3½ inches per watering (see par. 13), it would appear that a little over three waterings, on the average, were given, which is probably correct. Taking a greater number of days (than 152) for the season would increase the values of q and q_c; but, if irrigation went on for a longer period, it would be only fair to assume that more waterings would be given to some of the fields; this would increase the average number of waterings as well as the consumption of water per acre without altering the "duty." It is evident from Colonel Brownlow's remarks that fewer waterings were given at the ordinary time; the above calculation gives corresponding results, and so far supports the author's previous deductions.

27. In the second instance the result—65,000 cubic feet per acre (q)—may be distributed in the following manner:—D = 12 cubic feet per second = 432,000 cubic feet in 10 hours, the consumption daily. Mean distance of the fields from the tank was two miles; though as much as two miles of distributary and ten village watercourses, each say half a mile long, would be running at one time to irrigate 20 acres daily, on the average. Then the area over which loss has to be distributed was :—

			π		Sq. feet.	Total.
Distributary ...	2 ×	5280 ×	7	=	73,920	153,120 sq. ft.
Village channels	10 ×	2640 ×	3	=	79,200	

Then, taking for one trial a depth of 4 inches for a watering, and in another $4\frac{1}{2}$ inches (supposing half the land to be excessively sandy, as much of it was), the depth lost in channels would be 11 inches in the first case and $8\frac{1}{4}$ inches in the second, thus :—

——	First Supposition.		Second Supposition.	
	Depth.	Quantity.	Depth.	Quantity.
	inches.	cubic feet.	inches.	cubic feet.
Utilised in 20 acres	4	290,400	$4\frac{1}{2}$	326,700
Lost over 153,000 sq. ft. ..	11	141,600	$8\frac{1}{4}$	105,300
Total consumption	—	432,000	—	432,000

28. For the application of the foregoing results to Australia or to other countries than India, certain local information is necessary. First, in order to estimate the quantity of water required for actual irrigation (excluding loss by percolation) it is necessary to ascertain, besides the nature of the soil, what crops are to be irrigated, the number of waterings to be given to each, the intervals between the waterings and at what season water will be required. The author would then allow for each watering a depth of from 3 to 5 inches, according to the soil, as shown in Appendix A. If excess of water is to be used to save labour without any compensation in other ways, a larger supply would have to be allowed, according to the extra time the water would be flowing on any plot of ground (see column 7 of Appendix A). The result arrived at by multiplying the quantity consumed per acre each time by the number of waterings and by the area, will give the total quantity of water required for irrigation, including only loss in the field-channels up to a length, say, of 150 yards. More water might be used for the first watering of a crop (called in N. India *paleo*), but less would generally suffice afterwards, unless the ground were continually stirred up, or the upper crust repeatedly broken by hoeing. For the first few years the consumption of water might, and probably would, be in excess of this estimate, but good management should bring it down.

29. To estimate the loss by percolation from a canal and distributaries, the nature of the soil passed through

by the various channels, the approximate depth of soil and the nature of the subsoil, must be ascertained. Then, take the mean wetted perimeter of the canal and each distributary and multiply it by the respective length of each and by the number of days water would be flowing during the irrigating season. Allow a loss according to the scale given in Appendix A (cols. 2 and 3) over the whole wetted surface of bed and slopes of all channels.* If the soil or subsoil in which the canal is carried is an open or loose gravel or is much fissured and of considerable depth, a much larger loss than given by the scale may be expected; such places should be avoided if possible. In a narrow valley, or where an impervious substratum lies a little below the canal bed, or at a greater depth but rising on both sides so as to confine the subterranean current, or where the subsoil is less pervious than the surface soil, the loss would probably be less. Where, however, canals of any size are likely to be made, the country would be more or less open and the underground current practically unrestricted. After a few years the loss might be expected to decrease, owing to the pores of the subsoil becoming clogged.

VI.—Concluding Remarks.

30. The author has for several years watched carefully the working of various irrigation projects, and made inquiry into the causes of failure in certain cases. As a contribution to a subject on which but little is accurately known, loose generalisations being usually accepted, he thinks it right to make public the results of his observations, imperfect as they are; others can then make use of them or not as they please. Much difference of opinion may be expressed regarding the real value of the data accepted by the author, and the conclusions he has arrived at—(he will be glad to see these fully criticised), but he would urge on those having better knowledge of the subject, that the results of their observations should at the same time be given in a form suitable for the object of this paper—to serve as a guide for engineers in other countries than their own, epsecially in countries like Australia, where irrigation is in its infancy. Appendix A

* Where experiments on the absorbing power of the soil can be made in the manner described a little further on (see par. 33), it would perhaps be more satisfactory to base calculations of loss on the results so obtained.

should be considered as merely tentative—to be replaced by a better scale when fuller information is available.

31. However vague and imperfect the results given in this paper may be considered, it should not be forgotten that the same points have been hitherto not less vaguely dealt with (see par. 3), and that, moreover, irrigation is not singular in this respect. In many engineering calculations there is often very great latitude allowed in the shape of co-efficients, the value of which depends on the judgment of the one using them ; as, for instance, in calculating discharges of an irregular channel, of a channel when partially obstructed and, generally, whenever the conditions are complicated, as in practice they often are. Many other points, especially in hydraulic engineering, might be mentioned, such as the proportion of rainfall flowing off the surface of the ground for the supply of a reservoir, the volume of sewage it is necessary to provide for in any case, and others which will readily occur to an engineer.

32. Further investigation being very desirable, or rather essentially necessary, a few remarks on the point may be useful. When measuring the quantity of water used in irrigation, in order that results obtained in different localities may be compared, the author would suggest that the following particulars be noted :—Volume of water supplied, length of channel from the point of gauging the discharge to the field, mean wetted perimeter of channel, whether the channel is old or newly formed, and whether puddled in any way or not, average size of the beds in the fields, or the approximate number per acre, how long one bed takes to fill, how many previous waterings have been given to the same crop, at what intervals and how long since the last, whether or not the watercourse has been used just before for another field or otherwise, if the field has been hoed or the surface of the ground disturbed since the last watering, height of the crop or the extent to which it shelters the ground, nature of the soil, state of the weather at and just before the time of watering, date of measurement, and such other information as the observer may deem likely to affect the result. For want of full particulars, results hitherto obtained in different places are often not comparable. If, moreover, the observer would endeavour to apportion the total consumption between the fields and the watercourses in each case, somewhat after the example given above (see par. 27), it is probable that correct information would be obtained

quickly, since errors would be detected at once, and unusual results would lead to further inquiry.

33. The author's experiments on absorption before alluded to (see par. 19) were conducted as follows:—Several beds, formed by little ridges of clay, and measuring inside 4·8 feet square, were kept supplied with water; five gallons were poured on at a time, each gallon over the area enclosed giving a depth of one-twelfth inch. The object was to ascertain how long it would take for the soil to absorb given quantities of water. A somewhat similar arrangement might be adopted to ascertain the absorbing powers of any soil; but a measurable depth of water should be maintained, say not less than one inch; in the author's experiments this was not done. It would be well to note the quantities poured on in given periods, in order that it might be seen when, the absorption having assumed its normal rate, the experiment might be discontinued. At first, absorption would be very rapid, but it would soon decrease. Evaporation during the day, especially in hot weather, would be found to affect the result. In these experiments the following points should be noted:—Nature of soil, nature and depth of subsoil, and the general formation of the substratum in the neighbourhood, with any other points affecting the escape or retention of subsoil water; a natural drainage channel or other depression in the ground close by would be likely to assist very materially the escape of subsoil water. The results of these observations would, as a rule, apply only to the case of a canal, and not to a site likely to be selected as suitable for a tank (see pars. 24 and 29).

33. In conclusion, the author will offer a few remarks on the importance of the results brought to notice in this paper with reference to contemplated irrigation works in Australia. A canal may of course be constructed, and water supplied for irrigation, notwithstanding very erroneous notions as to the quantity of water required for various crops, the area likely to be irrigated, and on other similar points; but as all such works partake more or less of a commercial nature—a fair return for the outlay being in some form or other expected—it is important that a trustworthy estimate should be formed, or disappointment is likely to result. It is very unpleasant to find, after constructing a long canal, that water will not reach the end of it, that the supply is sufficient for only one-half or one-third of the area it was hoped to irrigate, and that in consequence of

various mistakes, instead of a profit of 5 or 10 per cent, only $\frac{1}{2}$ per cent. is realised, or, perhaps, the working expenses not even covered. These things have happened in India and elsewhere. It is not much consolation to be told that in 20 years' time the estimate may be fulfilled; and yet it is on results given by old canals, without proper correction, that estimates for new ones are often based, forgetting that usually it takes several years for irrigation to become fully developed.

APPENDIX A—*Empirical Scale for estimating the depths and quantities of water lost by percolation, and consumed in the irrigation of fields, in certain specified soils, where better information is not available.**

Class and nature of soil.	Loss by absorption or percolation daily.† Depth (see par. 16).	Loss by absorption or percolation daily.† Quantity per mile for each foot in width of wetted perimeter.	Loss by evaporation (see par. 22).	Consumption of water in the irrigation of fields.‡ When flowing for a few minutes only into each separate division of field (see pars. 12 and 13). Depth of watering.	Consumption … When flowing for a few minutes … Quantity per acre each time.	Extra quantity per acre, when flowing for a considerable time, including evaporation. For each hour *after* ground is saturated.	Extra quantity … For a continuous flow. First 24 hours.	Extra quantity … For a continuous flow. Each succeeding 24 hours.	Remarks.
	Inches.	Cubic feet.		Inches.	Cubic feet.	Cubic feet.	Cubic feet.	Cubic feet.	
1—Pure sand. Nothing grows on it, except where a little soil may have collected on the surface or just below it	36	15,840 or, say, 16,000	This may ordinarily be estimated at about ¼-inch, or, say, 100 c. ft. per mile for each foot in width, daily. The wetted perimeter of channels, as for percolation, should be taken. In rice irrigation the loss would probably be less than ¼-inch daily.	—	—	—	—	—	No cultivation possible unless other materials be mixed with it, when the soil would become that classed as 2.
2—Excessively sandy soil. Very poor; in its natural state, a long coarse grass or some sort of scrub may be found on it; when manured and cultivated, light crops may be produced. This is known as *bhoor* land in N. India	18	8,000		5	18,150	2,760	84,398	66,248	On these soils a continuous flow of water should be avoided, if possible, owing to great percolation.
3—Light sandy soil. No mixture of clay perceptible; when cultivated, fair crops may be grown	9	4,000		4	14,520	1,399	48,098	33,578	
4—Soils containing a mixture of sand and clay—									
a—Sand largely predominating, forming, with manure, a light loam, and producing very good crops	$4\frac{1}{2}$	2,000		3	10,890	719	28,132	17,242	
b—Sand and clay in about equal parts, forming, with manure, a rich loam—perhaps the best for general farming	$2\frac{1}{4}$	1,000		3	10,890	378	19,965	9,075	These soils, with the next (5), crack when dry, allowing water to run to waste; hence extra allowance made for irrigation.
c—Clay largely predominating, forming under cultivation a heavy loam	$1\frac{1}{8}$	500		4	14,520	208	19,511	4,991	
5—Almost pure clay. Found in low, marshy localities, and unsuited, as a rule, for any culture but that of rice§	$\frac{1}{2}$	220		5	18,150	100	20,550	2,400	Loss by evaporation assumed to be less than for other crops (see par. 22).

* See par. 30 and App. D. † See pars. 29 and 33. ‡ See pars. 28 and 32.

§ After this ground has been flooded for rice, a depth of ·66 inch daily flowing on to it has been allowed to keep up the supply, giving a "duty" of 36 acres per cubic foot per second; Col. Baird Smith estimated that a depth of ·62 to ·68 inch was consumed. See *Italian Irrigation*, Vol. II., pages 101 and 106.

APPENDIX B.

Calculation of the Average Loss of Water by Percolation from the Ganges Canal during the Cold Season of 1875-76.

Let D = mean discharge flowing during the season (152 days) = 4447 c. ft. per second. This may have been gauged in the main canal, thus including loss in the canal itself (case A), or more probably (case B), the gauging may have taken place at the distributary heads, thus excluding loss in the canal (see par. 7).

A = area irrigated during the season = 571,907 acres.

a = ,, ,, per c. ft. per sec. of discharge = A ÷ D = 128·6 acres.

Q = average quantity of water consumed daily on the whole canal = 4447 × 86,400 = 384 million c. ft.

q = quantity consumed per acre = 152 Q ÷ A = 102,000 c. ft.

q_c = quantity used in the fields per acre (51,000 c. ft.—see par 13) = $q \div 2$.

q_a = quantity per acre lost before reaching the fields (51,000 c. ft. —see par. 15) = $q \div 2$.

Q_a = quantity lost daily on the canal, bearing the same proportion to Q that q_a does to q ∴ $Q_a = Q \div 2$ = 192 million c. ft.

Q_c = quantity used daily in the fields = $Q - Q_a$ = 192 million c. ft.

l = average length in miles of channels (large and small) traversed by the water from the point where it is gauged to the fields, after allowing for closures (*tátils*) during the season.

π = wetted perimeter of various channels in feet.

M = miles of wetted surface of channels one foot in width = $l \times \pi$.

w = wetted surface in sq. feet = 5280 M.

d = depth in feet lost by percolation daily.

Then—

——	Total lengths in operation.	l	π	$M = l \times \pi$. Case A.	$M = l \times \pi$. Case B.
	miles.	miles.	feet.		
Canal	579	400	100	40,000	..
Distributaries ..	3386	2500	12	30,000	30,000
Village watercourses.	(See	below.)		30,000	30,000
Totals				100,000	60,000

The length of village watercourses has been assumed at 3 or 4 miles per mile of distributary, and π = 3 or 4 feet; then, area is about the same as that of distributaries. Field-channels (see 3*d*, par. 4) are not included.

From the foregoing the following average depths are obtained:—

——	Q_a	M.	Loss per M per diem = $Q_a \div$ M.	Depth lost per diem (d) = $Q_a \div$ 5280 M.
	mill. c. ft.		c ft.	feet. inches.
Case A	192	100,000	1921	·3638 = 4·366
Case B	192	60,000	3202	·6064 = 7·277

These are the average depths over the whole wetted surface in cases A and B respectively, lost by percolation (see par. 16).

APPENDIX C.

Calculation of the Loss of Water by Percolation in the first part of the Ganges Canal.

(*For Symbols, see Appendix B.*)

The volume of water (D) passing down the canal in December, 1860 (see "Pro. Inst. Civil Engineers," vol. 27, p. 509), was found to be —— at the head, Hardwar, 6710 c. ft. per second, and at Roorkee, 6283 c. ft. per second, giving a loss of 427 c. ft. per second in this length of about 18 miles. The loss really took place in 15 miles, or probably less, where beds of sand and boulders are crossed. The depth of water in the canal was from $8\frac{1}{4}$ ft. to 9 ft., making $\pi = 175$ ft. Then $w = 15 \times 5280 \times 175 = 13{\cdot}86$ mill. sq. ft., and $Q_a = 427 \times 86{,}400 = 37$ mill. c. ft. $\therefore d = Q_a \div w = 37 \div 13{\cdot}86 = 2{\cdot}66$ ft. At the Ratmu river it must have been much more—probably over 3 feet.

At the same time, 31 miles below Roorkee, D = 5279 c. ft. per second, showing a further loss of 1004 c. ft. per second. A portion of this was used for irrigation, though probably not more than 400, or, say, 500 c. ft. per second. The larger quantity would leave 500 c. ft. per second as the loss by percolation in the 31 miles, giving an average depth (d) of a little over $1\frac{1}{2}$ ft. daily; though, owing to the consumption for irrigation being uncertain, this result is open to question. Between the 30th and 40th miles, where a sandy tract of country is crossed, the depth would be in excess of the average, and doubtless fully $1\frac{1}{2}$ ft.

APPENDIX D.

Calculation of the Probable Depths of Water Lost by Percolation in Various Soils.

Taking the figures given in App. B, the average depth lost over the whole wetted surface of canal, distributaries and watercourses (case A) was ·3638 ft.—or, more probably, the canal not being included (case B), ·6064 ft.—over wetted surface of distributaries and watercourses only.

In light sandy soil the duty obtained from the water (see par. 9) was 72 acres, making the consumption per acre $= aq \div 72 = 183{,}000$ c. ft. Since the quantity used in the fields in sandy soil has been taken at 72,000 c. ft. per acre (see par. 13), that lost by percolation would be $183{,}000 - 72{,}000 = 111{,}000$ c. ft. per acre. It may be assumed that the depth percolating through a light sandy soil would bear the same ratio to the average depth lost in the canal as the loss per acre in the light soil (111,000 c. ft.) bears to the average loss per acre (51,000 c. ft.—see q_a, App. B). Then—

c. ft.		c. ft.				
As 51,000	:	111,000	: :	·3638 ft.	:	·792 ft.—case A.
				·6064 ft.	:	1·320 ft.—case B.

Now, since the loss per acre in light soil is based on the results obtained in the Anupshahr division of the Ganges canal, in which sandy soil largely predominates, though there is also some clayey soil, it is fair to assume that, had the soil been entirely sandy, the loss would have been greater. Assuming case B as the correct one (see par. 7), it will probably not be thought too much, after reading the instances of loss mentioned in the paper (pars. 18 to 21) and in Appendix C, to take the loss, in what in App. A (class 2) is termed an excessively sandy soil, at $1\frac{1}{2}$ feet per diem. This result may be considered as of general application in India or elsewhere.

The loss in clayey soil is not so easily estimated. The Cawnpore division of the Ganges canal, as a type of a mixed sand and clay soil, shows a duty of 149 acres per c. ft. per second (see par. 9), making the consumption per acre $= aq \div 149 = 88{,}000$ c. ft. Calculating as above (in the case of a sandy soil), the depth would be ·523 ft. in case B; but, as far as present information goes, this is too vague to be of much use. The loss in pure clay is practically nil; but a slight admixture of clay reduces materially the percolation through a sandy soil. On the whole, perhaps, the empirical scale given in App. A is as near an approach to a correct estimate as is possible at present (see par. 30). It will at any rate be better than taking one depth for any mixture of sand and clay, irrespective of the proportions. If further inquiries are carried on as recommended in the paper (par. 33), more definite results may be obtained in time.